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Delaminating Control on Drilling the Medium Density Fiber Board with Robust Optimization

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Abstract

Drilling the medium density fiber (MDF) board always emerge the occurrence of delaminating, as the unwanted result of the process. The defect will moderate the aesthetical value of the finished products particularly if the product is a furniture product. This work optimizes the control factor of delamination using robust engineering technique founded by Genichi Taguchi, father of robust engineering. The optimum drilling parameter which based on smallest the better is optimized and it is confirmed by the confirmation experiment that the imperfections is minimized. Three control factors are investigated in the study: feed rate, cutting speed, and drill bits diameter. The response plot of the control factor shows a drill bit diameter is the highest contributing control factor that influences delaminating as the different of the robustness is 2.047 dB. The optimum parameter shows that the variability of the noise factor is improved as compared to the initial parameter by means of the dB gain of 1.308 dB and 1.451 dB for the prediction and confirmation respectively. The robust assessment of the optimization has indicates that the drilling parameter is less sensitive to the noise factor.

Keywords: Medium density fiber board; drilling; robust; Taguchi

Abstrak

Mengerudi papan berserat ketumpatan sederhana akan sentiasa terdedah kepada masalah dilaminasi, iaitu suatu hasil yang tidak dikehendaki. Kecacatan ini akan mengurangkan nilai estetik produk akhir terutamanya sekiranya produk tersebut adalah perabut. Kajian ini telah mengoptimumkan faktor yang mengawal dilaminasi menggunakan teknik kejuruteraan robust yang dipelopori oleh Genichi Taguchi, bapa kepada kejuruteraan robust. Parameter optimum pengerudian yang berdasarkan kepada yang terkecil terbaik telah dioptimumkan dan ianya telah disahkan oleh eksperimen pengesahan bahawa ketidaksempurnaan tersebut telah dikurangkan. Tiga faktor kawalan telah diteliti dalam kajian ini iaitu: kadar suapan, halaju pemotongan, dan diameter mata gerudi. Plot respon bagi faktor kawalan menunjukkan diameter mata gerudi adalah yang lebih menyumbang kepada delaminasi tersebut disebabkan perbezaaan robustnya ialah 2.047 dB. Parameter optimum menunjukkan bahawa keragaman factor hingar telah dipertingkatkan berbanding parameter terdahulu dengan pencapaian sebanyak 1.308 dB dan 1.451 dB bagi eksperimen jangkaan dan pengesahan masing-masing.

Kata kunci: Papan berserat ketumpatan sederhana; pengerudian; robust; Taguchi

1.0 INTRODUCTION

Medium-density fiberboard (MDF) is an engineered wood product formed by breaking down hardwood or softwood residuals into wood fibers, often in a defibrator, combining it with wax and resin binder, and forming panels by applying high temperature and pressure. MDF is denser than plywood. It is made up of separated fibers, (not wood veneers) but can be used as a building material similar in application to plywood. It is much denser than normal particle board. The name derives from the distinction in densities of fiberboard.

Nowadays, MDF is widely used in furniture industries because of its favorable properties such as surface characteristics dimensional stability and excellent machinability [1]. Drilling is one of the most important processes in furniture industries. There are many undesired defects on drilled MDF products which will affect its final products appearance. One of the defects among the others defect is delamination [2,3]. Delamination reduces of aesthetic value and reduces product tolerance during assembly process. Parameters' involving drilling is the main problem. Until now, there are no specific parameters that can ensure a better finish after drilling nor the robustness of the parameters are not discussed in any publications. Most researches are focusing on reducing defects. The parameters of drilling materials are differing between one to another.

There are experiments reported by many authors on the use of Taguchi method for the machining process optimization such as by Ghani *et al*. [4], Moshat *et al*. [5], Gopalsamy *et al*. [6], Akhyar *et al*. [7] and Mustafa [8]. Their studies has indicated that feed rate, cutting speed and depth of cut are among the common cutting parameters used in the optimization [4,5,6,8] except literature [7] has included type of tool as another parameter for the optimization. Although, most literatures are reporting their works on machining melt materials, except work by Prakash *et al*. [9] is on the MDF, the results however is relevant to show the significance of the use of the Taguchi method in the machining process optimizations.

Authors of the literatures [4&6] has demonstrated that cutting speed is the most dominant parameters to minimize the surface roughness, whilst feed rate and cutting depth are discussed by literatures [7] and [8] respectively. However, literature [9] which is related with MDF indicates that the feed rate is the most significant cutting variable which also similar to the findings reported by literature [7]. These indicate that robust engineering optimization with Taguchi method has been proven by other literatures as feasible tools to optimize the machining processing parameters.

Hence, since most literatures are deals with melt materials and very few reported on the MDF materials except by literature [1&9], it is significant to optimize the drilling parameter of the MDF, and this article elaborates the robust optimization assessment of such materials. In the nutshell, the objective of this study is to optimize the drilling parameter using robust assessment methodology which also known as a Taguchi method and finally proposes the optimum cutting parameter that minimizes the variability of the noise factor and lastly reduces delamination during drilling process.

The scope of the optimization is limited only to the drilling process, while the ideal function/response is the delamination ratio. The contributions of the drilling parameters to the ideal function/response are also discussed in this paper. Such information is crucial for manufacturers as it helps to classify the most important control factors to drilling process. In MDF drilling, the machining ability is strongly dependent to cutting parameters, cutting forces, and cutting tool [10]. Drilling is significantly affected by the delamination tendency of the materials. Delamination caused by the cutting conditions in which the chisel edge of the twist drill cannot cut through to the materials [3], is the characteristic feature in drilling of MDF, which affected significantly by the cutting conditions. This condition occurs because of the localized bending in the zone situated at the point of attack of the drill [1]. The uncut material by the twist drills, which reduces strength against fatigue, is also the possible caused to the delamination of the hole and as a result it affects the assembly due to poor tolerance.

■2.0 MATERIALS AND METHOD

Medium density fiber (MDF) board was used in the experiment and the holes were drilled using Adcock Shipley machine with spindle speed ranges from 250 to 3750 rpm and feed rate from 0.0015 to 0.04 mm/rev. The MDF board prepared for the experiment was 100×100×25 mm and the modulus of elasticity was 2900 N mm^{-2}, humidity 8-10% and density was 0.07 kg/m^3. The L_{27} Taguchi's orthogonal arrays were used in the experiment and they consist of ranges of three level drilling control factors as shown in Table 1. The delamination was observed using NK Vision Microscope model NZM 70 45-T1.

Table 1 Parameter-level of drilling process

Control Factors	Units	Levels 1	2	3
A: feed rate (f)	mm/min	100	300	500
B: drill diameter(d)	mm	4	8	12
C: cutting speed (v)	mm/min	1000	6000	10000

■3.0 RESULTS AND DISCUSSION

Delamination is defined as a ratio of excess diameter (defects) against the actual diameter of the holes. The ratio of delamination is obtained when the excess diameter of defects is divided over the diameter of its actual holes, D/Dmax as shown in Figure 1. The measured delamination based on the $L_{27}(3)^{13}$ orthogonal array experimental setting is shown in Table 1. This delamination is considered a defect that has to be minimized and the smallest the better signal to noise ratio (eq. 1) is considered. The signal to noise ratio is an indexed of robustness. It measures the quality of energy transformation that occurs within processing parameter. The main purpose of robust engineering optimization is to minimize the loss imparted by the products to the society from the time the products are shipped [11, 12]. In addition, the noise condition for this experiment such as variation of MDF materials quality, spindle vibration, tool wear, ambient temperature and humidity is compensated in the experiment while the energy function is the torque delivered by the spindle.

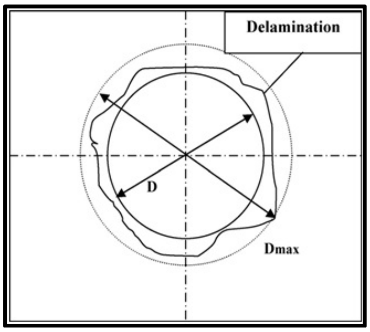

Figure 1 Delamination (mm) of the board.

$$S/N = -10\log\left(\frac{1}{n}\sum_{j=1}^{n} X_{ij}^2\right) \tag{1}$$

where X_{ij} is the delamination ratio and n is the number of replication for each run. The S/N ratio and mean for each run is as shown in Table 1.1. The high S/N ratio indicates low variability of the noise factor and thus it is robust. The robustness of the control factor is indicated by its S/N ratio [13]. As shown by Table 1.1, the experiment combination of run number 9 with combination of A1 B3 C3 is the robust combination with low variability to the noise factor.

Table 1.1 The delamination, x_n(mm), S/N ratio (dB) and mean (mm)

Runs	1 x_1	2 x_2	3 x_3	4 x_4	5 x_4	S/N Ratio (dB)	Mean (mm)
L1	1.787743	1.383353	1.620823	1.42459	1.493654	-3.80110	1.54
L2	1.257341	1.38342	1.873414	1.287592	1.258149	-3.11553	1.41
L3	1.813808	1.205587	1.233139	1.490085	1.391779	-3.18955	1.43
L4	1.509947	1.630983	2.184354	1.59202	1.667303	-4.77870	1.72
L5	1.205676	1.374406	1.042426	1.279399	1.011427	-1.51624	1.18
L6	1.275358	1.159351	1.154706	1.199366	1.076059	-1.39902	1.17
L7	1.015671	1.134175	1.172936	1.289254	1.407283	-1.66509	1.20
L8	1.125226	1.154258	1.126466	1.171517	1.245245	-1.32929	1.16
L9	1.245245	1.050498	1.09043	1.10627	1.247188	-1.22054	1.15
L10	1.209261	1.76306	1.57151	1.709272	1.773109	-4.18496	1.61
L11	1.493945	2.159603	1.219552	1.422018	1.172259	-3.72153	1.49
L12	1.452945	1.592034	1.927689	1.67864	1.147786	-3.97831	1.56
L13	2.310627	1.507591	1.208849	1.40327	1.850207	-4.61366	1.66
L14	1.211213	1.323338	1.218375	1.12129	1.120261	-1.59265	1.20
L15	1.782769	1.176936	null	1.189801	1.009374	-1.45998	1.03
L16	1.339552	1.482153	1.144868	1.350906	0.793572	-1.90702	1.22
L17	1.233978	1.234319	1.497547	1.243997	1.122699	-2.09347	1.27
L18	1.209719	1.104859	1.130208	1.27551	1.061728	-1.28121	1.16
L19	1.588859	2.073171	1.836461	1.942249	1.556701	-5.15629	1.80
L20	1.427507	1.829462	2.088952	1.599433	1.745609	-4.87245	1.74
L21	1.463134	1.374093	1.746459	1.63082	1.64986	-3.96570	1.57
L22	1.825361	2.085566	1.350861	1.68087	1.989357	-5.12930	1.79
L23	1.157068	1.875903	1.233507	1.563802	1.235033	-3.15976	1.41
L24	1.021649	1.200661	1.39184	1.047849	1.248346	-1.50997	1.18
L25	1.394722	1.239739	1.376763	1.616431	1.222468	-2.78065	1.37
L26	1.200877	1.191324	1.10272	1.339191	1.181126	-1.62316	1.20
L27	2.045881	1.14204	1.603284	1.237585	1.424596	-3.66292	1.49

The response graphs shown in Figure 2 indicates, A1 B3 C3 is the optimum drilling parameter that gives less variability to the noise factor for minimizing delamination of the MDF. The optimum parameter is focuses to the highest S/N ratio as it indicates the more robust the function. As shown in Table 1, experiment combination number 9 that indicates the highest S/N ratio and coincidently the optimum parameter is the same as shown in Figure 2. The S/N ratio is also defined as a ratio of efficiency and variability. Figure 2 shows that the optimum drilling parameter that minimizes the delamination ratio will improve the drilling efficiency and thus minimizes the waste of machining power that constitutes to the energy function of the scope of optimization. The response plot shown in Figure 2 shows that the feed rate should be kept as low the low level and the cutting speed is at the high level. This is in agreement with findings published by Gaitonde *et al*. [1].

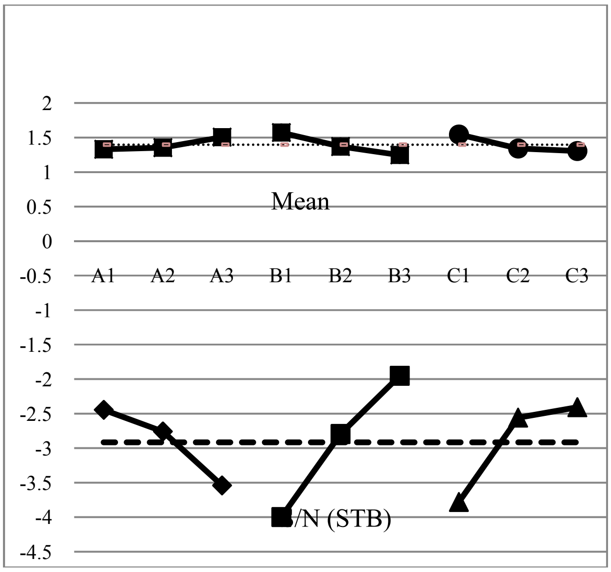

Figure 2 Control factor's response plot (a) Mean (mm), (b) Signal Noise ratio (dB)

The control factor's response table in Table 2 shows the largest difference between all levels of given factor. It represents the strength of effect for each factor. As shown in Table 2, drill diameter has strong effect to the delamination ratio, followed by cutting speed and feed rate. This signifies that the drill diameter is the control factor that needs much attention by the manufacturer. However, from another study by Prakash *et al.* [9,14] and, Prakash & Palanikumar [15] on the experimental studies on surface roughness in drilling of the same materials, feed rate is the most significant control factor followed by drill diameter and spindle speed. The different of the result is partly contributed by the density of the MDF as mentioned by Lin *et al*. [16] that they found board densities have a major influence on the machinability characteristics of the boards.

Table 2 Response Table (a) Signal Noise ratio (dB), (b) Mean (mm)

a. S/N ratio (variability analysis). Average = $\overline{T}$=-2.91511dB

Level	A feed rate	B drill diameter	C cutting speed
1	-2.446	-3.998	-3.78
2	-2.759	-2.795	-2.558
3	-3.54	-1.951	-2.407
Delta Δ	1.094	2.047	1.372
Rank	3	1	2

b. Mean. (mean analysis). Average = $\overline{T}$= 1.396891

Level	A feed rate	B drill diameter	C cutting speed
1	1.33	1.572	1.545
2	1.354	1.371	1.341
3	1.506	1.247	1.305
Delta Δ	0.176	0.325	0.24
Rank	3	1	2

The prediction of the optimized S/N ratio is done based on the response of the control factor shown in Figure 2. The initial prediction and conformation value shown in Table 3 is based on the current drilling parameter used before robust optimization was done, while the prediction and conformation optimum parameter is based on the optimum drilling parameter obtained based on Figure 2. A gain between the initial parameter to the optimal parameter of the prediction and conformation is 1.308 dB gain and 1.451 dB respectively.

Table 3 Prediction and conformation

	Prediction S/N (dB)	Confirmation S/N (dB)
Initial parameter	-2.28177	-2.1755
Optimum Parameter	-0.97377	-0.72467
Gain	1.308 dB	1.451 dB

■4.0 CONCLUSION

Robust engineering optimization based on Taguchi method has optimized the delamination ratio of the drilled MDF. The optimization has optimized A1 B3 and C3 as the optimum control factor for minimizing delamination and a drill diameter is the most influential control factor. The optimization is confirmed by the confirmation experiment with a gain of 1.451 dB which stronger than the prediction gain. In addition, by comparing the initial parameter and the optimum parameter, the optimum parameter's signal to noise ratio are more robust to the noise factor. This has concluded the objective of this work is achieved because the confirmation experiment is confirmed very well as the dB gain for the confirmation experiment is higher than the prediction ones. It shows that the confirmation dB gains show its robustness over the prediction ones.

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